Environment Canada Imaging Cover Page

Report N.: *TEC-779*

SKP Box Number: 672672428

ATMOSPHERIC ENVIRONMENT SERVICE
DEPARTMENT OF THE ENVIRONMENT – CANADA

Technical Memoranda

AN ANALYSIS OF OBJECTIVE WINTERTIME FORECASTS OF PRECIPITATION PROBABILITY AT SIX AIRPORTS IN BRITISH COLUMBIA

by

M. ROSE and L. PARENT

U.D.C. 551.509.324.2

TEC 779
11 OCTOBER, 1972

ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
Downsview, Ontario

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ABSTRACT

A program has been developed to prepare objective probability of precipitation forecasts at six airports in British Columbia. An explanation of its development and results of a three month operational run are discussed.

UNE ANALYSE DES PRÉVISIONS OBJECTIVES D'HIVER SUR LES PROBABILITÉS DE PRÉCIPITATIONS À SIX AÉROPORTS DE COLOMBIE-BRITANNIQUE

par

M. Rose et L. Parent

RÉSUMÉ

Un programme a été mis au point pour préparer les probabilités objectives sur les prévisions de précipitations à six aéroports de la Colombie-Britannique. On y étude une explication de sa mise au point et les résultats de trois mois d'operation.

AN ANALYSIS OF OBJECTIVE WINTERTIME FORECASTS OF PRECIPITATION PROBABILITY AT SIX AIRPORTS IN BRITISH COLUMBIA

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M. Rose and L. Parent

(Manuscript received June 27, 1972)

1. Introduction

Parent and Rose(1) have reported on the use of a multivariate discriminant analysis (MDA) technique to predict probability of precipitation during the summer at Vancouver and Prince George Airports. This report extends the study to the 'winter months' of February, March and April, and to four additional locations, the airports at Cranbrook, Revelstoke, Prince Rupert and Penticton.

2. Predictors in Discriminant Analysis

As reported earlier, the dependent variables were centered twelve hour precipitation amounts and mean centered twelve hour cloud amounts. The probability of occurrence of cloud and precipitation was forecast for the six airports listed above. In all, 83 predictors were screened to determine those best suited to the MDA technique at these places. Prognostic data as well as actual data were considered in this process. The former included vertical velocity and relative humidity taken from the U.S. primitive equations (PE) model. Predictors of the second type included initial values of sea-level pressure and 500 mb. height, sea-level pressure gradients as measured by pressure differences at some 14 observing sites, and 500 mb. wind speed and direction at seven upper air stations 'upstream', near or in British Columbia. North-south and east-west components of these winds were also considered. Ten predictors were chosen for each station and discriminant analysis was made on the basis of 'rain' or 'no rain' and 'cloud' or 'no cloud', the latter being defined as less than seven tenths of low and middle cloud.

3. Results on Dependent Sample

The dependent data set covered the period February-April 1971. Prediction equations were derived for both parameters at Vancouver, Prince George, Penticton, Cranbrook and Prince Rupert. At Revelstoke the precipitation MDA was done in conjunction with a Rogers Pass snowfall study and cloud data were not available in time to prepare equation for use in the operational runs.

At Prince George, discriminant functions were developed for cloud and these were included in the operational runs. Unfortunately, restricted use of the computer prevented a printout of the individual results on the dependent data set, and hence no contingency table could be prepared.

The results of an analysis of performance on the dependent data set in the form of contingency tables with percentage correct are in Appendix 1. MDA probabilities of 50% and over were verified as forecasts of occurrence, 49% or less as non-occurrence for both cloud and precipitation. Skill scores as defined by Brier and Panofsky (2) for the dependent sample are in Appendix 6.

The standard MDA significance statistic, the Mahalanobis D^2, as discussed by Miller (3) was computed for all cloud and precipitation functions and a table of these results is in Appendix 5. The generalized Mahalanobis D^2 can be used as chi-square (under assumption of normality) with M (g-1) degrees of freedom to test the hypothesis that the mean values are the same in all the g groups for these M variables.

In our case, the value of chi-square for 10 variables and 2 groups at the .05 significance level is 18.3 and at the .01 significance level it is 23.2. Typical values we have calculated range from 50 to near 200 and are, therefore, highly significant.

In addition, at Vancouver Airport an analysis was made on the basis of three categories. These were defined as 0-2 tenths, 3-7 tenths, and 8-10 tenths for mean cloud amount and nil, Tr-.24, and .25 or more for precipitation. This three-way analysis was intended to provide a quantitative estimate of cloud amount and precipitation in ranges that were meaningful, considering the climate of the station. In this three group MDA, the group for which the probability was highest was verified. This probability could be as low as 34% if the remaining groups had individual probabilities of 33%.

Because the contingency tables in Appendix I display results obtained by using the prediction equations on the dependent data sample, two features should be noted. The totals of the 'actual' rows give the frequency of each category in the sample. The figures in the boxes represent a near optimum level of effectiveness for the technique, using these predictors. Subsequent study has shown that a screening technique using an equal number of cases in each group can give better results in some cases and this technique will be used to derive future functions.

4. Operational Use

The prediction equations derived above are used to produce guidance in real time at the Weather Office, Vancouver. Cloud and precipitation probability forecasts are produced by computer for twelve hour intervals centered 12, 24, and 36 hours from reference time. Forecast office technicians extract the data required in the programme twice daily, either from numerical prognostics or from observations at the main synoptic times of 0000Z and 1200A. This data base is also used in other office programmes. Operations technicians enter the data on paper tape at the terminal of the time-sharing computer system and run the operational programme. A sample of the print-out is given in Appendix 2.

5. Verification

Approximately 115 probability forecasts are prepared each 24 hours. These have been verified for the 90 day period from February 1, 1972, until April 30, 1972. The 12, 24 and 36 hour forecasts were scored separately to display the decrease in accuracy attributable to deterioration in the prognostic data fields used in the equations. Verification of these operational forecasts is given in Appendix 3. The corresponding skill scores shown are in Appendix 7. In deriving the equations, 'no cloud' was defined as 0-6 tenths inclusive. This bias was intentional since it is important in a predominantly cloudy environment to emphasize in the forecast even restricted amounts of sunshine. However, verification was based on a convenient manuscript summary maintained in the office for other purposes, and cloud amount in this summary was given only in terms of airways symbols. This had the effect of defining 'no cloud' as 0-5 tenths in the verifying data. When the technique is verified in this manner, a number of forecasts will be scored incorrectly. Since actual cloud amounts were readily available from the daily record of observations at Vancouver Airport, verification there was done in both ways, i.e., 'no cloud' was equated to 0-6 tenths of cloud as well as to 0-5 tenths. It was then possible to estimate the magnitude of the error attributable to symbolic verification. The results are given in Appendix 4; comparison with those in Appendix 3 shows, as expected, that the number of 'no cloud' occurrences is larger. The magnitude of the increase, about 30%, casts a little doubt on the effectiveness of the symbolic sky condition as a basis for verification. In all three time periods, a total of 17 forecasts of cloudy, considered correct on the symbolic definition moved into the incorrect category on the precise definition, but to compensate, 19 forecasts of 'no cloud' previously considered incorrect moved into the correct category. Overall, the percentage of correct forecasts and the skill scores differed very little from one system to the other.

At Vancouver, use of the proper verification basis reduced the subsequent agreement from 92% to 87% when cloudy weather was forecast and raised it when non-cloudy weather was forecast from 44 to 54%. Since the sample period was predominantly cloudy, correct forecasting of non-cloudy weather took on more importance and therefore precise verification placed the results in this category in a better light. However, with the increase in the number of days defined as non-cloudy, the extent to which non-cloudy days were correctly forecast dropped from about 84% in the approximate verification to 76% in the more precise one.

Considering all airports again, in the first twelve hour period, on the average 75% of the forecasts were correct in both categories (cloud and precipitation). This compared with the average optimum figure of 79% for cloud and 77% for precipitation derived from the dependent sample. In the second twelve hour period the average in both categories drops to about 72.5% and in the final period to 67.5%. These are averages only and, as can be seen from the tables, performance varies considerably with both category and station. At any given location there is frequently much more skill in forecasts of one of the two mutually exclusive possibilities than in the other.

For the 'rainy' airports, (Vancouver, Prince Rupert, and Revelstoke) the percentage of correct forecasts in the 'rain' category was higher than in 'no rain'. The reverse was true at 'dry' airports (Penticton, Cranbrook and Prince George). The climatological probability of rain is, of course, involved in this result. The skill scores remove this climatological factor. In general, on the dependent sample, at the rainy airports, there is more skill in forecasts of 'no precipitation' even though a greater percentage of the forecasts of precipitation were correct. At the 'dry' airports, there was also more skill in the forecasts of precipitation. The same pattern is noticable on the verified sample.

6. Sources of Error in the Operational Runs

In general, the forecasts showed lower skill than did the results on the dependent sample.

Possible reasons for deterioration in time are listed below:

(a) Dependent data were "perfect progs". Actual run time data were from forecast fields.

(b) Because of the amount of data necessary, grid point data was extracted from the prognostic forecast fields and linearly interpolated by computer.

(c) The dependent sample 500 mb. winds were from Radiosonde data whereas run time 500 mb. winds were from forecast 500 mb. height field gradients.

(d) The map scale of the forecast fields was 1 in 30 million and maps were very hard to read at times. Quality control checks indicated that errors could creep in due to illegible maps.

(e) In cases of missing surface P.E. model prognostics, the Vancouver forecast prognostics for the nearest valid time were used. This was usually an earlier prognosis valid 6 hours earlier, and in cases of missing 500 mb. maps, the CAO baroclinic 500 mb. prognostic maps were used. In cases of missing vertical velocity and relative humidity maps, the mean vertical velocity and relative humidity of the dependent sample was used for each station.

Of these reasons for poorer performance, the last is most significant. The vertical velocity and relative humidity correlate most highly with cloud and precipitation and the loss of maps of these fields was a significant drawback. However, only some 5% of these maps were missing.

One must examine the distributions of predictors to find other sources of error. The MDA technique essentially sorts between groups in the independent variable based upon the spread between groups in the dependent variables or predictors. The Mahalanobis D^2 is the standard test statistic used to determine if the independent variable groups are significantly well separated by the predictors to assess the performance of the technique on dependent data. The assumption of normality is that the distributions of the independent variable and the predictors are normal. This is, of course, not true for all the predictors, of for the cloud and precipitation distributions. For this reason, skill scores and per cent correct are also shown in the appendices.

7. Conclusions

It is apparent from the tables in the appendices that the skill scores on the operational runs are somewhat lower than those on the dependent sample.

The reasons for these lower scores are outlined in Section 6 (Sources of Error) above. The most significant reason, however, appears to be the inherent errors in prognostic fields. The operational results that have been scored are not a fair test of the MDA technique on independent data. It should be borne in mind that what have been scored are the results of a modified operational technique that cannot approach the scores on the dependent sample. Despite the lower skill scores on these real-time runs, the forecast probabilities mirror the forecast fields, and as such, provide an excellent first estimate for the operational forecasters. The forecasters are aware of the frequent uncertainties in forecast fields and use the probabilities in this light. A further point to note is that to score probability forecasts correctly, more sophisticated scoring systems should be used. We have scored as "correct" those forecasts of 50% probability and over that were coincident with an event and those forecasts of 49% and less that were coincident with a non-event. In fact, if the forecast probabilities are distributed normally, the "correct" forecasts based on this system should only average 75% correct.

The encouraging results on the operational runs, using in some cases substitute predictors, and in all cases, prognostic data, indicate that the MDA technique applied in this manner can be a very useful tool in aiding the forecaster.

APPROVED,

J.R.H. Noble,
Assistant Deputy Minister,
Atmospheric Environment Service.

7. References

1. Parent, L. and M. Rose., 1972: Precipitation Probability Forecasting in B.C. Using a Multivariate Discriminant Analysis Technique, Environment Canada, Atmospheric Environment Service, Technical Memoranda series, TEC 774.

2. Panofsky, H. and G.W. Brier., 1958: Applications of statistics to Meteorology, University Park, the Pennsylvania State University, pp. 224.

3. Miller., 1962: Statistical Prediction by Discriminant Analysis. Meteorological Monographs. Volume 4, No. 25.

APPENDIX 1

DEPENDENT SAMPLE

VANCOUVER AIRPORT

CLD

FCST

ACTUAL	C	N/C	T
C	72	16	88
N/C	21	69	90
T	93	85	178

Percent Correct 79%

PCPN

FCST

ACTUAL	PCPN	N/P	T
PCPN	79	12	91
N/P	16	71	87
T	95	83	178

Percent Correct 84%

THREE GROUP PROBABILITIES

CLD (TENTHS)

FCST

ACTUAL	8-10	3-7	0-2	T
8-10	56	22	7	85
3-7	11	20	9	40
0-2	1	13	39	53
T	68	55	55	178

Percent Correct 70%

PCPN
(Nil, 0-.24, Gt. OR = .25)
FCST

ACTUAL	HVY	LGT	NIL	T
HVY	18	6	0	24
LGT	15	43	9	67
NIL	1	16	70	87
T	34	65	79	178

Percent Correct 74%

DEPENDENT SAMPLE

PRINCE RUPERT AIRPORT

CLD FCST

ACTUAL	C	N/C	T
C	101	21	122
N/C	15	41	56
T	116	62	178

Percent Correct 80%

PCPN FCST

ACTUAL	PCPN	N/P	T
PCPN	114	9	123
N/P	14	41	55
T	128	50	178

Percent Correct 87%

REVELSTOKE AIRPORT

PCPN FCST

ACTUAL	PCPN	N/P	T
PCPN	61	17	78
N/P	14	86	100
T	75	103	178

Percent Correct 83%

PRINCE GEORGE AIRPORT

PCPN FCST

ACTUAL	PCPN	N/P	T
PCPN	63	20	83
N/P	38	57	95
T	101	77	178

Percent Correct 68%

DEPENDENT SAMPLE

PENTICTON AIRPORT

CLD FCST

ACTUAL	C	N/C	T
C	71	13	84
N/C	19	75	94
T	90	88	178

Percent Correct 82%

PCPN FCST

ACTUAL	PCPN	N/P	T
PCPN	44	15	59
N/P	30	89	119
T	74	104	178

Percent Correct 68%

CRANBROOK AIRPORT

CLD FCST

ACTUAL	C	N/C	T
C	56	16	72
N/C	31	75	106
T	87	91	178

Percent Correct 74%

PCPN FCST

ACTUAL	PCPN	N/P	T
PCPN	44	10	54
N/P	37	87	124
T	81	97	178

Percent Correct 74%

APPENDIX 2

DISCRIMINANT ANALYSIS GUIDANCE BASED ON 030000Z DATA

	WED NITE		THURSDAY		THU NITE	
	Prob of Cld	Prob of Pcpn	Prob of Cld	Prob of Pcpn	Prob of Cld	Prob of Pcpn
Vancouver	0.09	0.08	0.18	0.24	0.62	0.93
Prince George	0.40	0.52	0.52	0.72	0.62	0.79
Penticton	0.03	0.39	0.12	0.71	0.49	0.87
Cranbrook	0.19	0.18	0.26	0.26	0.47	0.50
Revelstoke	0.	0.22	0.	0.36	0.	0.83
Prince Rupert	0.54	0.37	0.70	0.61	0.80	0.87

ADDITIONAL VANCOUVER INFORMATION

	CLOUD AMOUNT PROBABILITIES			PRECIPITATION AMOUNT PROBABILITIES		
	0-2 Tenths	3-7 Tenths	8-10 Tenths	Nil	0-.25 Inches	=.25 Inches
Wednesday Night	0.63	0.25	0.12	0.81	0.10	0.04
Thursday	0.42	0.34	0.24	0.65	0.23	0.12
Thursday Night	0.05	0.40	0.55	0.01	0.16	0.83

APPENDIX 3

VANCOUVER FEB-APR 1972

PRECIPITATION

12 Hr. FCST

ACT	PCPN	NO PCN	TOT
PCPN	83	12	95
NO PCN	26	43	69
TOT	109	55	164

Percent Correct 77%

24 Hr. FCST

ACT	PCPN	NO PCN	TOT
PCPN	69	25	94
NO PCN	20	49	69
TOT	89	74	163

Percent Correct 73%

36 Hr. FCST

ACT	PCPN	NO PCN	TOT
PCPN	69	25	94
NO PCN	22	46	68
TOT	91	71	162

Percent Correct 71%

CLOUD

12Hr. FCST

ACT	CLD	NO CLD	TOT
CLD	89	38	127
NO CLD	7	30	37
TOT	96	68	164

Percent Correct 73%

24 Hr. FCST

ACT	CLD	NO CLD	TOT
CLD	68	56	124
NO CLD	5	34	39
TOT	73	90	163

Percent Correct 63%

36 Hr. FCST

ACT	CLD	NO CLD	TOT
CLD	66	57	123
NO CLD	6	33	39
TOT	72	90	162

Percent Correct 61%

VANCOUVER AIRPORT

FORECAST VERIFICATION FEB-APR 1972

THREE GROUP PROBABILITIES

CLOUD (TENTHS)

12 Hr. FCST

ACTUAL	0-2	3-7	8-10	TOT
0-2	8	4	1	13
3-7	5	25	14	44
8-10	6	33	64	103
TOT	19	62	79	160

Total Correct 61%

24 Hr. FCST

ACTUAL	0-2	3-7	8-10	TOT
0-2	7	5	0	12
3-7	9	24	12	45
8-10	11	44	47	102
TOT	27	73	59	159

Total Correct 49%

36 Hr. FCST

ACTUAL	0-2	3-7	8-10	TOT
0-2	7	4	0	11
3-7	12	25	9	46
8-10	15	38	49	102
TOT	34	67	58	159

Total Correct 51%

VANCOUVER AIRPORT

FORECAST VERIFICATION FEB-APR 1972

THREE GROUP PROBABILITIES

PRECIPITATION

12 Hr. FCST

ACTUAL	NIL	0-25	=.25	TOT
NIL	40	24	3	67
0-25	10	49	11	70
=.25	0	19	6	25
TOT	50	92	20	162

Total Correct 68%

24 Hr. FCST

ACTUAL	NIL	0-25	=.25	TOT
NIL	47	16	4	67
0-25	12	53	6	71
=.25	2	16	4	22
TOT	61	85	14	160

Total Correct 65%

36 Hr. FCST

ACTUAL	NIL	0-25	=.25	TOT
NIL	41	21	5	67
0-25	19	40	11	70
=.25	1	17	5	23
TOT	61	78	21	160

Total Correct 54%

SUMMARY OF FORECAST VERIFICATION

at

Penticton, Prince George, Cranbrook, Revelstoke, and Prince Rupert

AIRPORT	PER CENT CORRECT FORECASTS					
	12 hr. pcpn	fcst cld	24 hr. pcpn	fcst cld	36 hr. pcpn	fcst cld
Penticton	72	71	64	72	65	65
Cranbrook	69	75	62	69	60	65
Prince George	69	75	73	78	59	69
Revelstoke	76	-	79	-	72	-
Prince Rupert	87	81	82	81	83	77

APPENDIX 4

VANCOUVER VERIFICATION FEB-APR 1972
USING "NO CLOUD" 0-6 TENTHS
"CLOUDY" AS 7-10 TENTHS

12 Hr.
FCST

ACTUAL	CLD	NO CLD	TOT
CLD	84	31	115
NO CLD	12	37	49
TOT	96	68	164

Total Correct 74%

24 Hr.
FCST

ACTUAL	CLD	NO CLD	TOT
CLD	62	50	112
NO CLD	11	40	51
TOT	73	90	163

Total Correct 63%

36 Hr.
FCST

ACTUAL	CLD	NO CLD	TOT
CLD	60	51	111
NO CLD	12	39	51
TOT	72	90	162

Total Correct 61%

APPENDIX 5

VALUES OF MAHALANOBIS D^2 FOR DISCRIMINANT FUNCTIONS DEVELOPED ON DEPENDENT DATA SET

	PRECIPITATION		
Station	Mahalanobis D^2	Variables	Observations
Vancouver	195	10	178
Prince George	52	10	178
Penticton	76	10	178
Cranbrook	69	10	178
Revelstoke	158	10	178
Prince Rupert	140	10	178

	CLOUD		
	Mahalanobis D^2	Variables	Observations
Vancouver	97	10	178
Prince George	52	10	178
Penticton	105	10	178
Cranbrook	68	10	178
Prince Rupert	108	10	178
Revelstoke	(Not available)	--	---

APPENDIX 6

SKILL SCORES FOR DEPENDENT SAMPLE FORECAST

	PRECIPITATION			CLOUD		
STATION	PCPN	NO PCPN	TOT	CLD	NO CLD	TOT
Vancouver	.66	.72	.68	.55	.62	.58
Prince George	.30	.44	.35	(Not available)		
Penticton	.39	.56	.46	.60	.69	.64
Cranbrook	.34	.66	.45	.40	.57	.47
Revelstoke	.67	.62	.64	(Not Available)		
Prince Rupert	.65	.74	.69	.59	.51	.54

APPENDIX 7

SKILL SCORES FOR FEB.-APR. 1972

OBJECTIVE FORECAST VERIFICATION

PRECIPITATION FORECASTS

STATION	12 Hr. Pcpn	12 Hr. No Pcpn	12 Hr. Tot	24 Hr. Pcpn	24 Hr. No Pcpn	24 Hr. Tot	36 Hr. Pcpn	36 Hr. No Pcpn	36 Hr. Tot
Vancouver	.43	.62	.51	.47	.41	.44	.42	.39	.41
Penticton	.36	.48	.41	.22	.15	.18	.28	.24	.25
Cranbrook	.28	.64	.39	.17	.32	.22	.14	.30	.19
Prince George	.26	.52	.35	.16	.33	.22	.11	.25	.15
Revelstoke	.39	.52	.44	.44	.62	.52	.34	.40	.37
Prince Rupert	.63	.71	.67	.49	.60	.54	.43	.47	.45

CLOUD FORECASTS

	12 Hr. Cld	12 Hr. No Cld	12 Hr. Tot	24 Hr. Cld	24 Hr. No Cld	24 Hr. Tot	36 Hr. Cld	36 Hr. No Cld	36 Hr. Tot
Vancouver	.68	.28	.39	.71	.18	.29	.65	.17	.26
Penticton	.34	.48	.40	.39	.44	.41	.28	.31	.29
Cranbrook	.42	.54	.48	.33	.43	.37	.25	.33	.29
Prince Rupert	.70	.36	.47	.69	.35	.46	.69	.26	.37

CLOUD FORECASTS VERIFIED

(As cloudy 7-10 tenths)

	12 Hr. Cld	12 Hr. No Cld	12 Hr. Tot	24 Hr. Cld	24 Hr. No Cld	24 Hr. Tot	36 Hr. Cld	36 Hr. No Cld	36 Hr. Tot
Vancouver	.58	.35	.44	.52	.19	.28	.47	.17	.25

TEC 779 UDC.551.509.324.2
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